SYNOPSIS

ON

Study of Non-classical States of Light and Their Applications in the Field of Optical Telecommunication

SUBMITTED

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SYNOPSIS

Topic of the Ph.D.:

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1. Introduction:

With the invention of the laser in the 1960s, considerable interest has grown in the field of nonlinear optics because of its wide applications in many branches of science and technology such as in spectroscopy, optical correlation functions, photon anti-bunching, quantum degree of coherence of light, squeezing of the radiation field, statistical properties of the generated optical fields, etc.

Out of the above-mentioned phenomena, squeezing of radiation and photon anti-bunching [1-2] are of prime importance owing to its low noise property. It is a special class of minimum uncertainty states of the quantized oscillator, showing non-classical behaviour and can be represented by complex amplitude, which describes both the magnitude and the phase of the field. In the quantum mechanical description, the real and imaginary parts of this amplitude obey an uncertainty relation. The amplitude of the electromagnetic field is always quantum fluctuations.

The basic idea of squeezing is the reduction of quantum fluctuations in the quadrature component (either the amplitude or the phase) within Heisenberg's uncertainty relation. In a coherent state, the fluctuations in the quadrature components are equal and their product is the minimum uncertainty product given by Heisenberg's uncertainty relation and the quantum fluctuations of a coherent state are zero-point fluctuations and are randomly distributed in the field quadrature components. On the other hand, it is possible to have minimum uncertainty states having reduced fluctuations in one quadrature at the expense of other quadrature components. These states are called squeezed states, in which the quantum noise is not arbitrarily distributed in the field quadrature. Photon anti-bunching [1] measures the photon anticorrelation by which photon comes separately instead of a cluster. Quantum fluctuation is the fundamental property of any system and it is present also in the field vacuum state. These studies of quantum effects are important not only fundamentally but also have several possible potential applications in high-quality optical telecommunication [3], amplification of signals, interferometric technique (to detect very weak forces such as gravitational wave detection [4], high precision measurements [5], optical wave-guide tap [6], optical computing [7], the solution to cosmological problems [8], quantum cryptography [9], detection of biological tissues [10] and so on.

2. Preliminary review of literature/state-of-the-art:

Over the past three decades, a lot of work has appeared in the literature on the generation of squeezed states of the electromagnetic field and their experimental evidence and theoretical prediction by various nonlinear optical processes such as parametric amplification [11], harmonic generations [12-13], multi-wave mixing processes [14-15] and others. More recently, higher-order squeezing has been studied in various nonlinear quantum optical processes [16]. Due to their high nonlinearities, they can play an important role in the generation of squeezed light. Other types of higher-order squeezing like sum and difference of field squeezing were proposed by Hillery [17] for the two modes which are in fact the simplest versions of multimode higher-order squeezing. These concepts have recently been generalized to include three modes for sum and difference

squeezing [18] as well as an arbitrary number of modes for sum and difference squeezing [19]. More recently Mukherjee et al. [20] has reported the idea that sum-and-difference squeezing is possible in harmonic generation processes. Recently, Mishra et al. [21] have explored higher-order squeezing by the beam splitter with third-order nonlinearity.

The nonlinear response of the system to the radiation field plays a great role and represents a new type of quantum state of the electromagnetic field. Therefore, their study can be expected to lead to new fundamental insights.

3. Problem to be investigated:

Quantum low-noise is the fundamental property of any system and it is present in all kinds of field states, including the vacuum state. Light with unusual quantum fluctuation properties occurs in the form of squeezed light, photon antibunching, sub-Poisson photon statistics. Out of which squeezing of light has been generated in view of the possibility of reducing the noise of an optical signal below the vacuum limit. It has been drawing attention in nonlinear optics over the three-decade. Now till most theoretical and experimental investigations have been carried out exclusively in the time domain. These phenomena have several potential applications but are still to be considered for designing teleporting systems with non-classical states to improve the quality of the teleported quantum state. Hence in view of these problems our interest to investigate a novel type of light with very little quantum noise in various multi-photon nonlinear optical processes.

4. Objectives of the research:

The objective of this investigation will be to study a novel type of light with very little quantum noise by using nonlinear optical processes.

In the selection of nonlinear processes like harmonic generation processes, multi-photon processes will be given more emphasis because not much of work has been done on higher-order squeezing in these processes. In addition to other types of higher-order squeezing like sum of the frequency and difference of the frequency will be included. The dependence of normal squeezing on the higher-order squeezing or vice-versa will also be investigated In this process, various possibilities of producing squeezed radiation and dependence of squeezing on photon numbers will be established.

These studies may pave the way towards the generation of low noise squeezed radiation which will be useful in highquality telecommunication and related fields.

5. Research questions and or Hypotheses:

If the Glauber-Sudarshan function is negative or more singular than a delta function [1], a state is called a non-classical state. In these conditions, quasi-probability distribution is not accepted as classical probability and thus we cannot obtain an analogous classical state. As such squeezed state and photon anti-bunched states are well-known non-classical states. The squeezed state and photon anti-bunching of light is a type of non-classical state which is characterized by reduced quantum fluctuations in one quadrature of the field at the expense of the other quadrature field. The Anti-bunching of photons reflects the quantum nature regarding the generation of photons. That characterized as the probability of detection of a one-photon pulse which is greater than that of a two-photon in a bunch and i.e. greater than the probability of detection of a three-photon in a bunch and so on. Hence, photon anti-bunching measures the photon anti-correlation.

These two non-classical states have been studied for a long but the interest in higher-order non-classical states is relatively new.

6. Research design & Research methodology:

Our research will be based on the technique of setting up Hamiltonian for several multi-photons processes and establishing coupled Heisenberg equations of motion involving the real and imaginary parts of the quadrature operators under the short-time scale. These equations under a weak pump are exactly unsolvable. The short-time scale approach is simple and enables us to solve explicitly quantum statistics within the interaction time in a systematic way. When the photons number is very large ($|\alpha|^2 \gg 1$) and short-time scale $gt << 1$ ($gt \sim 10^{-6}$), it is possible to obtain much simpler approximate analytical formulas describing the variances of the operator. Such solutions give more information for detailed computations and also make it possible to determine the possible quantum states of the field exhibiting correlation bunching, full coherence anti-correlation, and anti-bunching. A nanosecond or picoseconds pulse laser may be used as the pump field. The computations in this work will be done by using MATHEMATICA software.

7. Tools to be used in the collection of data and analysis: Not applicable

8. Significance of proposed work:

Squeezed light with low noise in quadrature components has many attractive applications, like in optical telecommunication [3], in precision and sensitive measurements such as gravitational wave detection or in noise-free amplification of signals [4, 5], optical computing [7], cosmological problems solution [8], detection of biological tissues [10] and so on.

Higher-order antibunched light is a multi-photon version of anti-bunching which is useful as a single-photon source [22] for quantum cryptography [23, 24]. Now a days, entanglement in continuous-variable systems offer an advantage in quantum information, has been attracted pronounced interest in both theoretical and experimental work [25, 26]. Thus, generation and manipulation of non-classical states of continuous-variable systems are the important elements in the quantum information processing. These studies represent a new type of quantum state of the field and can be expected to lead to new fundamental insights. It has been of interest to the research community in the fields of quantum optics, nonlinear optics, atomic physics, molecular physics, and biological physics. These studies can lead to designing good quality of teleporting systems and may be expected for the fabrication of future teleporting devices.

9. Research limitations and future work:

The limitation of short-time approximation including real and imaginary parts of the coupling constant can be removed by using some mathematical technique. The phase dependence of the quadrature component may be included in the study. The research outcome would be utilized to work further in the field of quantum information and quantum computation. The scope of future work is manifold.

Future work appears in the following:

- Experimental verification of the theoretical results of the present work.
- Use of squeezed light and anti-bunching of light as resource in quantum teleportation.

These results offer the possibility of designing future teleporting devices and may be improving the performance of many optical devices and optical networks.

10. Tentative chapterizations:

Chapter 1: Introduction

Chapter 2: Higher-order squeezing of the field amplitude

Chapter 3: Higher-order antibunching of the field amplitude

Chapter 4: Squeezing, sub-Poissonian, and total noise of the quantum state

Chapter 5: Summary and Conclusions

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